RAYTHEON COMPANY
Research Division
131 Spring Street
Lexington, MA 02173

RF VACUUM MICROELECTRONICS

Quarterly Progress Report No. 6
July 1992 to December 1992

RAY/RD/S-4887 1 July 1993

Contract No.
MDA972-91-C-0032

Sponsored by

Defense Advanced Research Project Agency
Defense Sciences Office

I. EXECUTIVE SUMMARY

Raytheon

VHF micro-triode (cylindrical) cathodes tested in glass envelope at 5 mA of current and f_t of 100 MHz.

Low capacitance structures fabricated on sapphire substrate.

Extrapolated f_t from lowest C/tip and largest g_m/tip is 420 GHz.

Cornell

Cornell silicon tips tested at Raytheon.

II. MILESTONES STATUS

		Completion Date	
		Original	Act/Est
1. Moly Tip Field Emitter			
1.1	Process enhancement	2/93	02/93
1.2	Leakage current suppression	7/92	10/92
1.3	Series resistor development	9/92	11/92
1.4	Alternative Emitter materials	2/93	---
2. Wing Field Emitter			
2.1	Process development	4/92	stopped
2.2	Electrical tests	6/92	stopped
3. DC/Low Frequency Test			
3.1	Improve bakeout and turn on proc.	12/91	12/91
3.2	Life tests	2/93	---

4. High Frequency Design/Fab #1			
4.1	VHF micro-triode (cylindrical) design/fab	5/92	8/92
4.2	Planar micro-triode design/fab	5/92	8/92
4A. High Frequency Design/Fab #2			
4.1	VHF micro-triode (cylindrical) design/fab	-	1/93
4.2	Planar micro-triode design/fab	-	2/93
5. High Frequency Test #1			
5.1	Test VHF micro-triode	8/92	9/92
5.2	Test planar micro-triode	8/92	9/92
5A. High Frequency Test #2			
5.1	Test VHF micro-triode	-	2/93
5.2	Test planar micro-triode	-	2/93
6. Silicon Tip Development		2/93	2/93
7. Cantilevered Gate		2/93	----

III. TECHNICAL PROGRESS

Raytheon

1.4 - The carbide targets (Zirconium, Hafnium, and Tantalum) were ordered and received. A 3Å layer of HaC was deposited with no apparent electrical effect. The quality of the carbide targets does not appear to be good enough for our deposition technique. We must investigate other vendors and/or processing for the targets.

3.1 - A new capability was added to the low frequency/DC test set-up. All pulsed gate measurements have been made with the anode on 100% of the time. This is because there was no equipment that could switch the high voltage on a millisecond time scale. A new unit from DEI (Directed Energy Inc., Fort Collins, CO) allows the anode up to 5 KV and the gate to be switched simultaneously on a millisecond time scale.

3.2 - No long life tests have been run since the test stand is needed for all the other testing.

4A.1-2 - The masks for both *high frequency designs* (cylindrical and planar) were reworked for lower capacitance and higher density of tips.

5A.2 - All the prime parts for the reworked VHF micro-triode were designed and ordered and received. The I-V results for the latest tube (RD-11) and two earlier devices (RD-1,3) are plotted in Figure 1. The improvement with this latest lot of cathodes is quite good. The f_t from the I-V and capacitance data data is 100 MHz.

5A.2 - The cathodes from the planar design were RF probed up to 3 GHz and the capacitance values were extracted. Figure 2 shows the chip layout. The various test patterns yielded the capacitance of the leads and pads which then could be subtracted from the device measurement to yield the capacitance of only the emitters. The sapphire substrate data is summarized in Figure 3. The columns are related through the equation:

$$C_{tot} = K_{tips}(K_{layout}\, C_{||}) + C_{leads} + C_{pads}$$

The capacitance on the sapphire is about a factor of three less than the same structures on silicon.

This chips were not tested for emission before the end of the contract.

Other

The new evaporator (purchased with internal funds) has successfully made tips. This new machine will be a great help in process development and increased throughput.

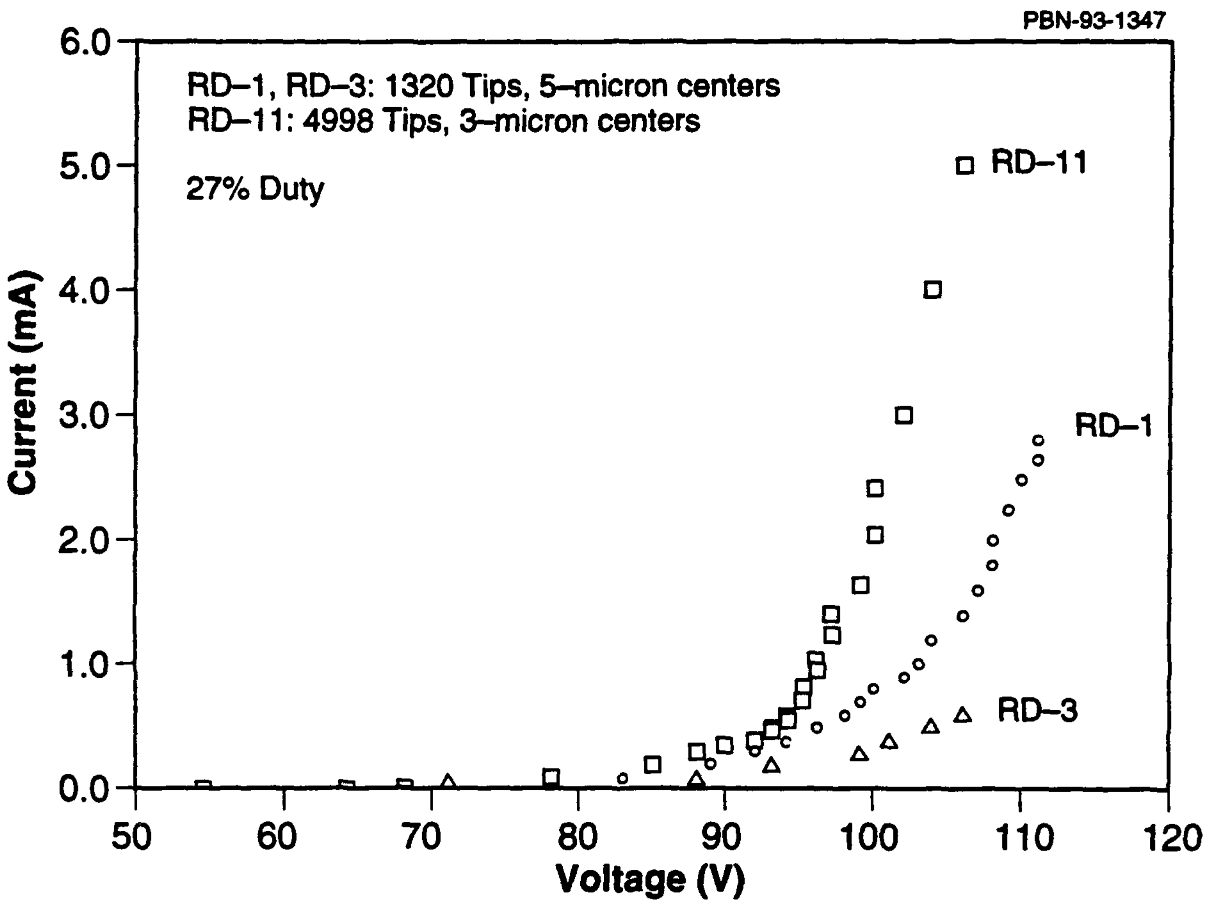
IV. FISCAL STATUS

V. PROBLEM AREAS

The requirement of $F_t > 1$ GHz was not met. The silicon chips from Cornell never produced high currents. The best result obtained with the cylindrical (tube type) design was 100 MHz. The best extrapolated result from the best planar capacitance and best g_m (different wafers) was 420 MHz. A variety of parameters need improvement to obtain the program goal of f_t of 1 GHz and the desired goal of over 10 GHz. The current per tip must be increased and the turn on voltage must be decreased.

VI. VISITS AND TECHNICAL PRESENTATIONS

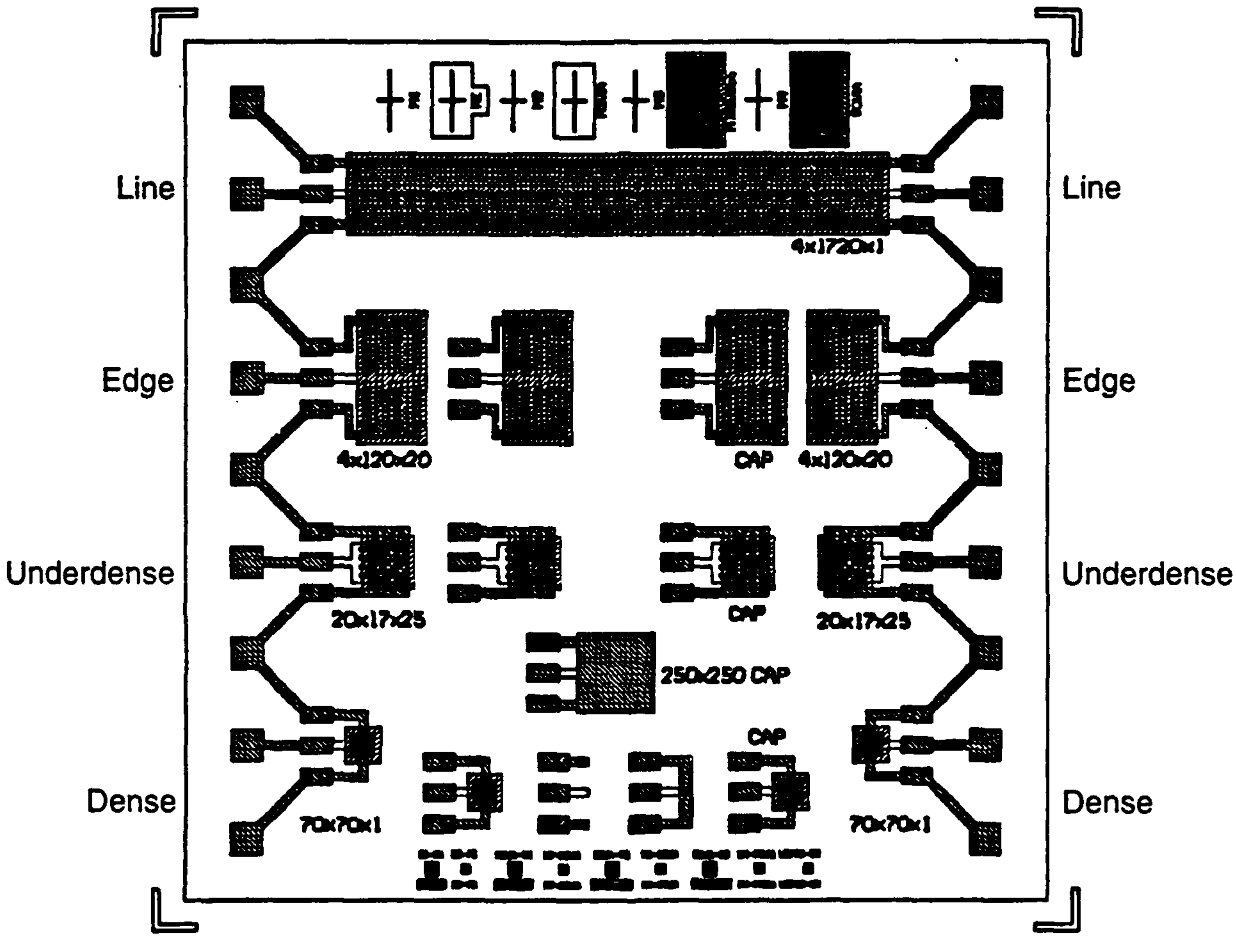
Raytheon presented a site review to DARPA on February 2, 1993.



Cathode style	Annular Ring 4998 tips on 3 µm centers
Capacitance	1.2 pf
Current	5.0 mA
Gate Voltage	106 V
Anode Voltage	800 V
Transconductance	0.20 mS
Duty	27%
F_t	100 MHz

Figure 1. RD-11 Cylindrical Triode.

PBN-93-1349



RF Test Structures

Figure 2. Planar Triode Test Chip.

PBN-93-1348

Device Type	Tip Pitch (μm)	$C_{\|\|}$ (pF) calc.	K_{layout} calc.	C_{device} calc.	K_{tips} calc.	C_{leads} (pF) meas.	C_{pads} (pF) meas.	C_{tot} (pF) calc.	C_{act} (pF) meas.
20 Edge	4	.40	1.6	.64	.80	.03	.02	.56	.53
20 Edge	3	.40	1.6	.64	.61	.03	.02	.44	.47
20 Edge	2.5	.40	.16	.64		.03	.02		
25 sqr	4	.35	1.2	.42	.80	.03	.02	.39	.42
25 sqr	3	.35	1.2	.42	.61	.03	.02	.32	.38
25 sqr	2.5	.35	1.2	.42		.03	.02		
Dense	4	.20	1.0	.20	.80	.03	.02	.21	.20
Dense	3	.20	1.0	.20	.61	.03	.02	.17	.15
Dense	2.5	.20	1.0	.20		.03	.02		

Figure 3. Capacitance Evaluation Data on Sapphire Substrate.

CONTRACT NO: MDA972-91-C-0032
CONTR. TITLE: RF VACUUM MICROELECTRONICS
CONTRACTOR: RAYTHEON CO., RESEARCH DIV.

DATE PREPARED: 28-Jun-93
REPORT PERIOD: 05/03/93-05/30/93

FUNDS AND MANHOUR EXPENDITURE REPORT

CONTRACT VALUE:	$1,095,328
CURRENT FUNDING (sell):	$1,095,328
NEG. FEE RATE:	0.0%
% FUNDING SPENT & COMMITTED:	96.0%

	CONTRACT VALUE	REPORTING MO. EXPEN-DITURES	CUMULATIVE EXPEND. TO DATE	% $ VALUE	COST TO COMPLETE ESTIMATE	LATEST COST ESTIMATE	PREVIOUS COST ESTIMATE
A	B	C	D	E	F	G	H
TOTAL PRIME LABOR HOURS	7,467	6	6,572		79	6,651	6,895
TOTAL PRIME LABOR	$203,891	$153	$179,718		$2,166	$181,884	$190,609
LABOR OVERHEAD	$362,926	$265	$314,400		$4,135	$318,535	$335,399
TOTAL LABOR & OVERHEAD	$566,817	$418	$494,118		$6,301	$500,419	$526,008
MATERIALS	$220,841	$26,464	$241,184		$0	$241,184	$229,017
ODC	$830	$0	$2,453		$0	$2,453	$3,279
IWR	$135,944	$0	$155,925		$16,429	$172,354	$173,300
PRODUCT COST	$924,432	$26,882	$893,680		$22,730	$916,410	$931,604
G & A	$148,407	$3,937	$137,459		$3,206	$140,665	$145,380
COM	$22,489	$43	$20,322		$221	$20,543	$22,029
TOTAL COST LEVEL	$1,095,328	$30,862	$1,051,461		$26,157	$1,077,618	$1,099,013
FEE	$0	$0	$0		$0	$0	($3,685)
TOTAL CONTRACT PRICE	$1,095,328	$30,862	$1,051,461	96.00%	$26,157	$1,077,618	$1,095,328
OUTSTANDING COMMIT.		$0	$0				
TOTAL COMMIT & EXPEND.	$1,095,328	$30,862	$1,051,461	96.00%		$1,077,618	$1,095,328

ACT=AA